Nucleon-Deuteorn Scattering Studied by the Quark-Model Baryon-Baryon Interaction

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The three-nucleon ($3N$) system is appropriate to study the nucleon-nucleon (NN) interaction since many techniques for rigorous calculations are developed. The quark-model (QM) baryon-baryon (BB) interaction describes available experimental NN data and hyperon-nucleon data with high accuracy [1]. The most recommended model fss2 gives in the NN sector accuracy comparable to modern realistic meson-exchange potentials. The QM BB interaction is constructed in the framework of the resonating-group method (RGM) for two three-quark clusters. The short-range repulsion of the NN interaction is mainly described by the nonlocal quark-exchange kernel, which gives quite different off-shell properties from the standard meson-exchange potentials. The energy dependence of the interaction inherent to the RGM formalism is eliminated by the standard off-shell transformation, which yields an extra nonlocality [2]. The deficiency of the triton binding energy by fss2 is about 350 keV [3], which is far smaller than 0.5 – 1 MeV predicted by the standard meson-exchange potentials. It is therefore interesting to examine the nonlocal effect of QM NN interaction on the $3N$ scattering observables.

In this study, we have applied our realistic QM NN interaction fss2 to the neutron-deuteron (nd) and proton-deuteron (pd) scattering in the Faddeev formalism and examined various scattering observables [4]. The NN interaction up to G-wave ($I_{\max}$=4), which corresponds to $(E_N)_{\max} \sim 65$ MeV, is included in these calculations. The screened Coulomb force at the nucleon level, which is derived from the sharply cut-off Coulomb force $(1/r)\theta(\rho - r)$ at the quark level, is used for pd scattering [5]. In the most of the pd elastic calculations, we choose the Coulomb cut-off parameter $\rho = 8$ or 9 fm. The off-shell property of fss2 appears in the low-energy region of the ${}^2S_{1/2}$ channel, in conjunction with the almost correct value of the triton binding energy [3]. This feature is due to the strong distortion effect of the deuteron, which is caused by the non-local description of the short range repulsion of the NN interaction. Consequently, the ${}^2S_{1/2}$ eigenphase shift predicted by fss2 is sufficiently attractive to reproduce the phase shift analysis as well as the small value of the nd doublet scattering length [6]. The diffraction minima of the pd scattering are well reproduced so long as the incident proton energy is not too high ($E_p < 35$ MeV). The too-small peak height in the low-energy nucleon analyzing power $A_y(\theta)$ is slightly improved. Various polarization observables of the nd and pd elastic scattering and deuteron breakup differential cross sections are rather similar to the predictions by meson-exchange potential and the effective chiral NN interaction including the disagreement of some particular observables like the A_y puzzle and the space star anomaly.

We have also examined the cut-off parameter dependence on the scattering observables [5]. Some kind of stability against the change of ρ is required, since the ultimate limit $\rho \to \infty$ is not possibly achieved numerically. We find that the relative angular momentum between two protons should be included up to large values in order to achieve such a stability. Further calculations using a larger model space with $I_{\max} = 5$ and 6 are required to eliminate the cut-off parameter dependence.

References

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